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Adaptive Suspension of Vehicles with New Principle of Action: Theoretical Bases and Experimental Investigations

A. Dubrovskiy, S. Aliukov, S. Dubrovskiy and A. Alyukov

***Abstract*—The development of any vehicle is always carried out under the condition of strict enforcement of certain, pre-set performance characteristics. A special place among them is occupied by the so-called running performance, which does not affect the assessment of the traction-dynamic parameters of the vehicle, its fuel economy, etc. The direction of our activity is the development of adaptive suspensions of vehicles of a new principle of action. Currently, a group of leading researchers of the Automobile and Tractor faculty of the South Ural State University has completed a large cycle of fundamental research work on the creation of adaptive suspensions of vehicles of a new principle of operation, allowing to adjust the performance of the suspension while the vehicle is moving, depending on road conditions, either in automatic mode or in manual control mode. We have developed, researched, designed, manufactured and tested the following main components of adaptive vehicle suspensions: adaptive, lockable shock absorbers and elastic elements with non-linear characteristics, which, in combination with their functional properties and performance characteristics, significantly exceed existing foreign analogues, not to mention domestic designs. To demonstrate these advantages, a full-scale stand of the chassis of the "right front quarter" of the VW PASSAT CC was created and comparative simulation tests of "moving the car over bumps" with a regular suspension and with a suspension equipped with elastic elements and adaptive shock absorbers of our structures were carried out. This paper analyzes the characteristics of the perspective adaptive shock absorber, in terms of use in the vehicle's suspension, with an ultra-wide range of performance adjustment. The article describes the stand and the results of comparative simulation, experimental studies of the dynamic characteristics of the "car" VW PASSAT CC with a standard suspension and with a suspension equipped with adaptive shock absorbers and elastic elements of our design..**

***Index Terms*— Vehicle, suspension, shock absorber, work characteristics, experimental investigations**

I. Introduction

WHILE designers create a suspension system of a vehicle, they always have to solve the problem of reconciling of two groups of conflicting requirements [1,2]:

1. Requirements to ensure a given level of smoothness, rapidity, minimize dynamic loads acting on the cargo, nodes, passengers and drivers of the vehicle;
2. Requirements of manageability, security, stability, stabilization of the vehicle, stabilization of its body.

Besides, it is well known that to reconcile the conflicting requirements mentioned above, it is possible to do the most effectively only if to provide the following three conditions:

1. The suspension system of the vehicle has to contain an elastic element with nonlinear characteristic [3].
2. The suspension system of the vehicle has to contain an adaptive shock absorber with ability to control its performance in accordance with traffic situation while the vehicle moves.
3. When designing the suspension system of the vehicle, it is necessary to ensure optimal coordination of the performance parameters of the elastic element with nonlinear characteristic and the adaptive shock absorber of the suspension of the vehicle, as well as to implement an optimal control algorithm for the adaptive shock absorber.

Analysis of existing approaches to solve this problem in the area of transport engineering practice has shown that there is no yet any optimal, economically acceptable solution for practical realization of these requirements, mentioned above, as well as implementation of these three conditions [4-7]. However, it seems that the implementation of our suggestions will significantly move towards the solution to this complex problem [8-11].

The main aim of our paper is to introduce working characteristics of our developed vehicle suspension and to show its advantages in comparison with existing ones. We do it on example of experimental research with Russian passenger cars named cars VAZ "LADA-GRANTA" and "LADA-KALINA."

There already are implementations of similar suspension system concepts in production vehicles today. For example, semi-active dampers with high operating ranges and algorithms that increase damper force have been known for more than 10 years. And dampers that incorporate hydraulic locking have been known for much longer. Non-linear springs and jounce bumpers that create rising wheel rate curves are also common. But for both the

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lockable damper with increased damping force near the end of the stroke and the non-linear torsion spring we have managed to find new solutions how to improve the efficiency of these units. We have got 9 patents on inventions for these devices with improved working characteristics.

This paper is composed of four sections. In the first section we point some main functional advantages of our developed designs. In the second section we describe experimental results for the front suspension of the car VAZ 2116 "LADA-KALINA." In the third part we consider some possibilities of usage of our vehicle suspension. And in the last section we investigate operating characteristics of the units of our developed suspension, such as, a lockable adaptive shock absorber and an elastic element with a nonlinear characteristic on the different modes of work.

II. MAIN FUNCTIONAL ADVANTAGES OF OUR DEVELOPED DESIGNS

Lockable adaptive shock absorber with a hyper-wide control range of dissipative characteristics

We list the main functional advantages of our developed shock absorbers in comparison with the existing designs.

1. They allow us to implement the hyper-wide control range of dissipative characteristics depending on value of the first control parameter, namely: the value of "control current" on a coil of electro-hydraulic valve:

- from characteristics of clearly specified, the lowest level of damping;
- to characteristics up to the highest level of damping mode until the "self-locking," when the shock absorber is converted into a single rigid unit, and thus it has an "very high level of damping."

2. They allow us to realize the "self-blocking" mode at any time.

3. Depending on the magnitude of the second control parameter, namely: position of piston, they can implement the following features:

- they allow us to implement any pre-defined dissipative characteristics of the marked hyper-wide control range of the dissipative characteristics in intermediate positions of the piston corresponding to "comfort zone";
- degree of damping of the shock absorbers automatically progressively increases while the piston is approaching to extreme positions, regardless of the magnitude of the control parameter, namely, value of "control current" on the coil of the electro-hydraulic valve;
- they are automatically "self-locking" in a unilateral direction in the extreme positions of the piston.

4. In total, the transition from conventional shock absorbers to usage of our proposed designs of the adaptive shock absorbers does not suppose any increasing of size of existing designs of regular suspension devices of vehicles, and it does not require any significant investments. «Issue price», basically, is the cost of the electro-valve, not taking software into consideration.

How can the shock absorber automatically switch operating modes between a softer and stiffer characteristic, which also includes a maximum "lockout mode"? To solve this problem we have invented new designs of the absorber. In the designs permitted tensions in elastic elements typically do not exceed 800 MPa. The internal pressures where this damper would be operating, during the "lockout mode" is low enough to provide reliable operating of the damper. We have proved this claim with help of experimental studies. What are the inputs that the damper is adjusting to? They are road conditions and modes of driving of the vehicle.

The resilient element with nonlinear characteristic and automatic optimization of localization of "working zones"

The developed designs of the elastic elements, unlike the well-known ones, have the following advantages:

1. They have significantly non-linear characteristic, which consists of several separate intervals.
2. The basic operating interval («comfort zone») has a very low stiffness. In existing designs we have decreased the stiffness in this interval more than two times in comparison with the known analogs.
3. The subsequent intervals have stiffness in several times larger than in the known analogs.
4. In «spring designs» conventional cylindrical springs with constant pitch winding and constant diameter of the wire are used.
5. The design of the elastic element allows automatically, consistently excluding from further work those intervals, tensions at which have reached a predetermined maximum value. In other words, the design of elastic elements possesses the peculiar property of automatically optimization of localization of the "working zones."

III. EXPERIMENTAL RESULTS

As an example, let us consider the developed experimental model of the elastic element for the front suspension of the car VAZ 2116 "LADA-KALINA" (Figure 1).

Elastic element of the car VAZ 2116 «LADA-KALINA» (prototype) has the following parameters:

$$F_{\max} = 5684.9 \text{ N};\ f_{\max} = 0.155 \text{ m};\ F_S = 3481.36 \text{ N};\ f_S = 0.048 \text{ m};\ c_p = 20.59 \text{ N/mm}.$$

Here f_S is deformation of the elastic element corresponding to static load F_S acting on the car; $f_{\max}$ is deformation of the elastic element corresponding to the highest load $F_{\max}$ acting on the car; and c_p is stiffness of the elastic element (prototype) of the car VAZ 2116 «LADA-KALINA".

Operating characteristic of the elastic element (prototype) is linear, and in Fig. 1 marked in red. But operating characteristic of the developed experimental model of the elastic elements for the front suspension of the car VAZ 2116 «LADA-KALINA" is nonlinear and consists of three line segments. In Figure 1 it is marked in blue.

Commenting on the main design features of the developed experimental model of the elastic elements, it is necessary to pay attention primarily on the following points:

1. In zone U_1 (zone of comfort) stiffness c_1 of the developed experimental model of the elastic element is 10.438 N/mm; consequently the ratio $K_c = c_1 / c_p$, where c_p is stiffness of considered part of the elastic element of the prototype, in this case is as follows

$$K_{c,U1} = c_1 / c_p = 0.522. \quad (1)$$

2. In zone U_2 of increased deformations the stiffness c_2 of the developed experimental model of the elastic element is 73 N/mm; consequently the ratio (6) in this case is as follows

$$K_{c,U1} = c_1 / c_p = 3.48. \quad (2)$$

3. In zone U_3 of high deformations the stiffness c_3 of the developed experimental model of the elastic element is 1610.438 N/mm; consequently the ratio (6) in this case is as follows

$$K_{c,U1} = c_1 / c_p = 76.7. \quad (3)$$

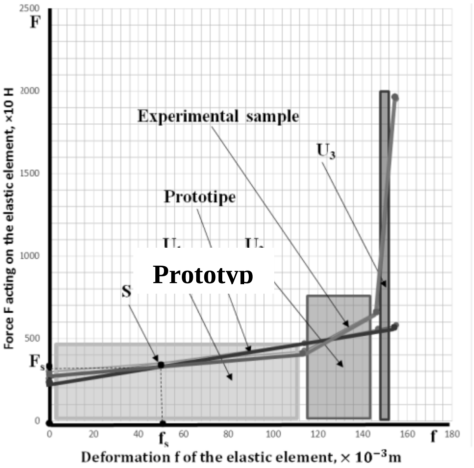

Fig. 1. Comparison of theoretical and experimental results

Thus, as expected, in a broad operational area in the comfort zone U_1, the stiffness of the suspension of the developed experimental model of the car, according to (1), almost is half the stiffness of standard suspension of the car VAZ 2116 «LADA-KALINA". That undoubtedly leads to qualitative improvement of the comfort of the car. However, in the zone of increased deformations U_2, according to (2), the stiffness of the suspension of the developed experimental model of the car is already 3.48 times higher than that of the standard. This fact facilitates faster "pacification" of vibrations of body of the car. And this property is even more enhanced in the zone U_3 of high deformations. In this zone, in accordance with (3), the stiffness of the suspension of the developed experimental model of the car is 76.7 times higher than that of the standard.

And it is very important that, as expected, in our developed designs of elastic elements, maximum stresses in these elements do not exceed 800 MPa.

Fig. 2 shows the experimental work characteristics of one of designs of the blocked adaptive shock absorber designed for rear suspension of the car Lada Kalina. This Figure indicates that the following has place: 1. The regulation of the work characteristics of the adaptive shock absorber is continuous (as opposed to stepped); 2. We can implement any characteristic of the set.

In Fig. 2 the characteristic r2 is working characteristic of shock absorber of rear suspension of the car Lada Kalina.

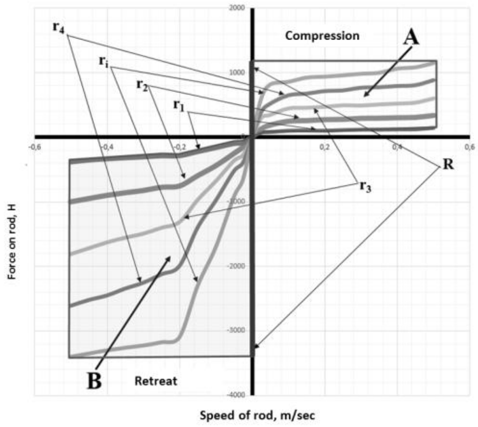

Fig. 2. Work characteristic of adaptive shock absorber

IV. POSSIBILITIES OF USAGE OF OUR DESIGNS OF THE VEHICLE SUSPENSION

Using of the proposed designs of the adaptive shock absorbers and the elastic elements will allow the following:

1. Highly effectively to solve the problem of improving sharply comfort, the smoothness of the vehicle, a significant reduction of dynamic loads acting on the cargo, passengers, crew, components and units of the vehicle, especially, when this vehicle is moving on a road with lower quality. It is provided by the fact that:

1.1. In the "comfort zone" the stiffness of the resilient suspension element is not less than two times lower than stiffness of the elastic elements of existing suspension systems.

1.2. In the "comfort zone" the shock absorber can automatically switch to operating mode with a softer characteristic.

1.3. Under any road conditions and at any time, the shock absorber can automatically implement the operation of suspension system of the vehicle according to any pre-formed program of optimal control. It is ensured by the presence of the hyper-wide control range of the operating characteristics. At the present, it is not available for existing analogues in the world practice of vehicle engineering.

2. Highly effectively to solve the problem of controllability, stability, and stabilization of the body of the vehicle when cornering, on a road with low quality, under action of short-term and long-term pulsed loads, during acceleration and braking of the vehicle. It is provided by the following:

2.1. In zone of higher deformation of the elastic element of the vehicle suspension, the stiffness of the elastic element is at least four times higher than the nominal stiffness of this elastic element.

2.2. In zone of high deformation of the elastic element of the vehicle suspension, the stiffness of the elastic element is no less than thirty times higher than the nominal stiffness of the elastic element. Note that at present, almost no one elastic element of mechanical type possesses the combination of the properties 1.2, 2.1, and 2.2 with additional restriction of largest allowable stress value of 800 MPa.

2.3. Under any road conditions and at any time, the shock absorber can automatically implement lockout mode in which it is converted into a single rigid unit, this property is particularly valuable when driving at high speed cornering, and the sudden acceleration or sudden braking. In these cases, to provide the stabilization of the vehicle body is the most important.

3. Highly effectively to solve the problem of increasing average speeds of the vehicle when driving on a road with lower quality, cornering, when both of the conditions limit the level of dynamic loads on the cargo, passengers, crew, components and units of the vehicle to maintain the set of indicators ride and stability control of the vehicle.

4. To use the automatic control of the adaptive suspension system of the vehicles, to implement adaptive stabilization of the vehicle, the stabilization of its body, optimizing of parameters of handling, stability and comfort of the vehicle by means of the most efficient and economical way. This improves the rapidity of the vehicle.

5. To exclude «breakdowns suspension» of the vehicle.

6. To eliminate the need of buffers rebound and compression.

V. OPERATING CHARACTERISTICS OF THE DEVELOPED UNITS OF THE ADAPTIVE SUSPENSION

The lockable adaptive shock absorber with a hyper-wide control range of dissipative characteristics

If we characterize the structure of a family of our developed adaptive shock absorbers, it can be concluded that structurally the shock absorbers consist of two interconnected main components:

- the actual shock absorber, i.e. piston-cylinder unit, and
- the electro hydraulic valve.

These two components have different effects on formation of four main variants of operational control of the work (dissipative) characteristics of the shock absorbers.

Firstly, we note that, in contrast to the well-known schemes, in the proposed design of the adaptive shock absorbers their work characteristic has the following structure:

$$Q = Q(\dot{q}, p), \quad p = col(q, i), \tag{4}$$

here

Q is the force acting on the piston of the shock absorber;

$\bullet \equiv \dfrac{d}{dt}$ is the operator of differentiation with respect to time t;

$p = col(q, i)$ is “control matrix” of the shock absorber - column matrix of size 2 × 1;

i is the value of the control current in the electro-hydraulic valve of the shock absorber (the first control parameter of the shock absorber);

q is a coordinate, determining the position of the piston 1 (Fig. 3) - the distance between this piston and its center position in the work cylinder 3 (the second control parameter of the shock absorber). In the Fig. 3 we have: 1 is the piston; 2 is piston rod; 3 is the work cylinder; 4,5 are back and front sides of the piston. In the Fig.3 the electro-hydraulic valve is not shown.

The main determining regulation component acting on the adaptive shock absorber is, of course, the magnitude of the control current. Mainly, it is variation of value of , that allows us to get the «infinite» (hyper-wide) control range of the dissipative characteristics of the adaptive shock absorber.

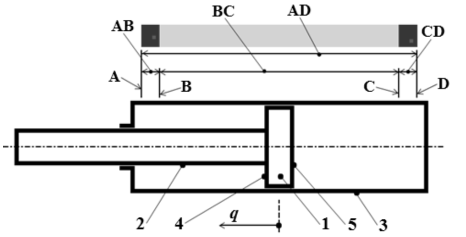

Fig. 3. Scheme of telescopic shock absorber

Depending on the type of function $i = i(t)$ and the method of its formation, four variants of the organization of the operational control of the dissipative characteristics of the shock absorber may occur:

1.1. Autonomous mode in which the controlled variable i is constant. This mode is the most simple design variant of the control of the dissipative characteristics of the shock absorber. It is realized by natural internal automatism. This mode is limited by zone BC (Fig. 3), and it is approximately 93-95% of the maximum stroke of the piston in compare with the total work area AD. In this mode operating characteristic of the shock absorber remains unchanged and consists of a single curve, namely: curve 1 in rebound phase, and curve 4 in the contraction phase (Fig. 4).

However, when the piston is crossing the boundary positions $q = 0.95 q_{\max}$, i.e. when the right side 5 of the piston 1 (Fig. 2) is crossing the point C, or when the left side 4 of the piston 1 is crossing the point B as during its further movement within the corresponding zones AB and CD (zones of intensive damping), up to the approaching of the piston to the extreme positions A and D. The developed design allows us to increase the degree of damping of the shock absorber automatically and progressively. Force Q, acting on the piston 1 (Fig. 3) and, consequently, on the rod 2, starts to increase as well. The corresponding curve of the characteristic starts to approach gradually to the y-axis consistently taking up the positions 1, 2 (Fig.4), etc.

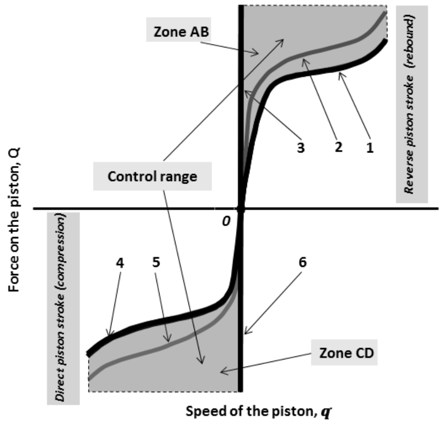

Fig. 4. Operating characteristics of the shock absorber at constant operating influence

In Fig. 3 and Fig. 4, the description of the “lockable adaptive shock absorber” is captured such that the non-linear ramping up of damping at the extreme ends of travel is equivalent in the compression side as it is on the rebound side.

Finally, in the limit, when the piston is in the leftmost position, in which the left side 4 of the piston takes the position A (Fig. 4), the characteristic will automatically be aligned with the upper beam 3 of y-axis. In this position it automatically occurs the mode of “self-blocking”, in which the shock absorber is converted into a single rigid element and the further movement of the piston 1 lefter position A is impossible.

The elastic element with a nonlinear characteristic and automatic optimization of the localization of the operating zone

In the following data to evaluate the effectiveness of our developed designs we compare the relevant characteristics of existing real prototypes traditionally used at present elastic elements with linear performance characteristics that work in similar conditions and have similar basic sizes. For a quantitative evaluation of the technical advantages of our designs of the resilient elements we consider the generally accepted valuation parameters:

$$c=\frac{dQ}{dq}, \tag{5}$$

$$k_d = Q_{\max} / Q_s, \tag{6}$$

$$R_d = \int_{q_s}^{q_{\max}} Q(q)dq - Q_S \cdot (q_{\max} - q_s). \tag{7}$$

Here we have:

Q is force on the elastic element;

q is deformation of the elastic element;

$Q_{\max}$ is maximum force on the elastic element;

$q_{\max}$ is maximum deformation of the elastic element;

Q_s is static load on the elastic element;

q_s is static deformation of the elastic element;

c is stiffness of the considered part of the elastic element;

k_d is dynamic factor;

R_d is dynamic capacity of the elastic element of the suspension.

In addition to the conventional parameters (5) - (7), we consider some additional relative values:

$$K_c = c_1 / c_p, \tag{8}$$

$$K_Q = Q_{\max,1} / Q_{\max,p}, \tag{9}$$

$$K_R = R_{d,1} / R_{dp}. \tag{10}$$

Here we have:

c_1 is stiffness of considered part of the experimental model of the elastic element;

c_p is stiffness of considered part of the elastic element of the prototype;

$Q_{\max,1}$ is the maximum force on the experimental sample of the elastic element;

$Q_{\max,p}$ is the maximum force on the elastic element of the prototype;

$R_{d,1}$ is dynamic capacity of the experimental sample of the elastic element of the suggested suspension;

R_{dp} is the dynamic capacity of the elastic element of the suspension of the prototype.

We have developed two designs of the elastic elements with non-linear characteristics and automatic optimization of the localization of the operating zones. These designs are fundamentally different from each other. Their operating characteristics are shown in Fig. 5.

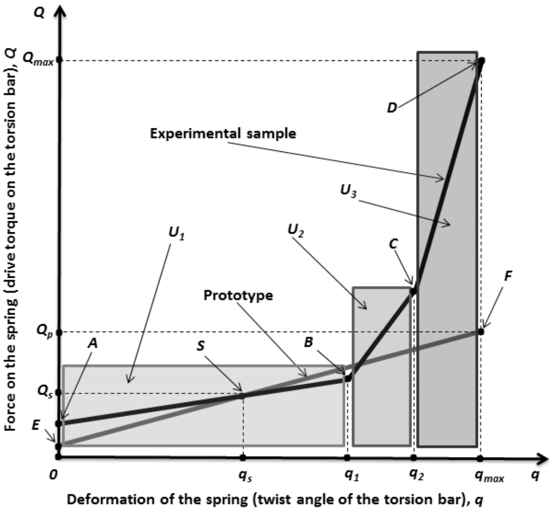

Fig. 5. Operating characteristics of the elastic element

The adaptive suspension of vehicle

Let us consider the operating characteristic of the elastic element under the assumption of using this element in conjunction with the adaptive shock absorber in the vehicle suspension. In fact, we consider adaptive suspension system of the vehicle, including the elastic element and the adaptive shock absorber.

Fig. 6 presents the linear characteristic of the prototype of the elastic element (line EF) and the combined operating characteristic of the experimental sample with the developed elastic element and the adaptive shock absorber (OASBCGD curve).

Thus, by using our developed elastic elements of the vehicle in the “comfort zone”, the suspension will be significantly softer, and, at the same time, and it will more effective solve the problem of stabilization of the vehicle and its body [12-14].

Fig. 7 illustrates the experimental stand for the shock absorber test. In Fig. 8 there is one the experimental characteristics of the shock absorber.

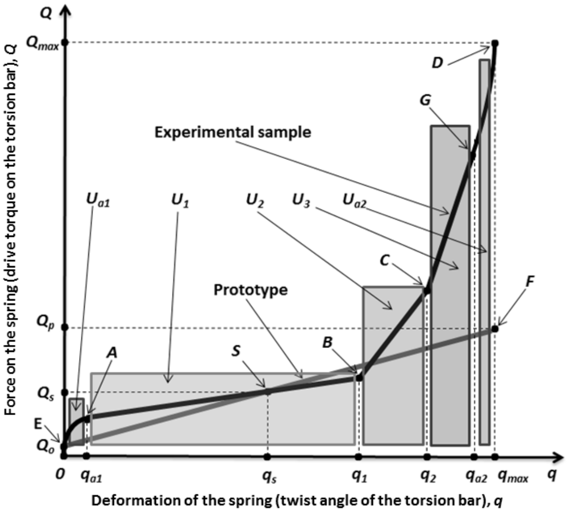

Fig. 6. Operating characteristics of the elastic element based on the availability of the adaptive shock absorber

Fig. 7. Experimental stand for the shock absorber test

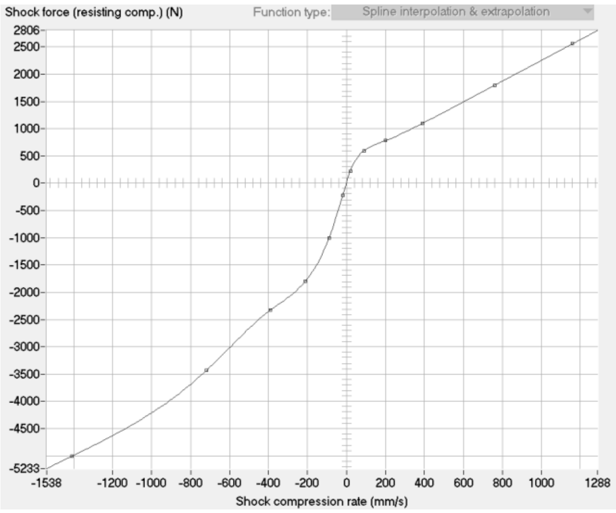

Fig. 8. Experimental characteristic of shock absorber

VI. FULL-SCALE STAND "RIGHT FRONT QUARTER" OF THE CAR VW PASSAT CC

The stand (Fig.9,10) includes a base 2, on which are mounted two symmetrically arranged vertical guides 1 of the movable load 3 - simulator of the “right front quarter” of the VW PASSAT CC car body. The lower bearing 4 (silent-block) of the right front suspension arm 5 and the upper support 6 of the shock absorber rack 8 of the right front wheel 9 are fixed on the movable load. A spring element (spring) 7 of the right front wheel is mounted on the shock absorber rack. The stand also includes a drive adjustable electric motor 10, a gear drive of the vibrator support 12, a sensor 11 "level" of the right front wheel, a sensor 13 measuring the force acting from the wheel 9 on the vibrator support 12, a sensor 14 measuring the "deformation of the wheel", monitor 15 a personal computer that registers the measured parameters and the unit 16 controls the degree of dissipation of the adaptive shock absorber and the oscillation frequency of the vibrator support.

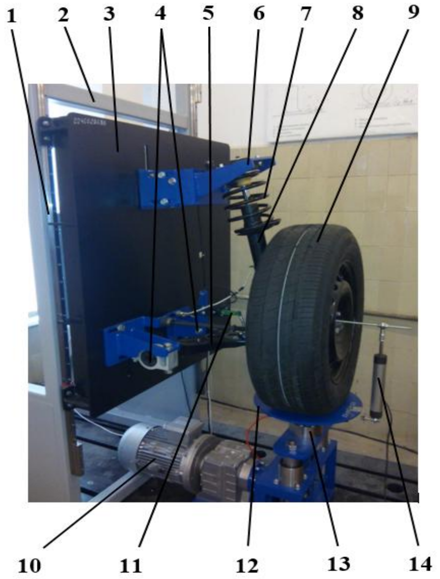

Fig. 9. Stand of the front suspension of the car VOLKSWAGEN PASSAT CC

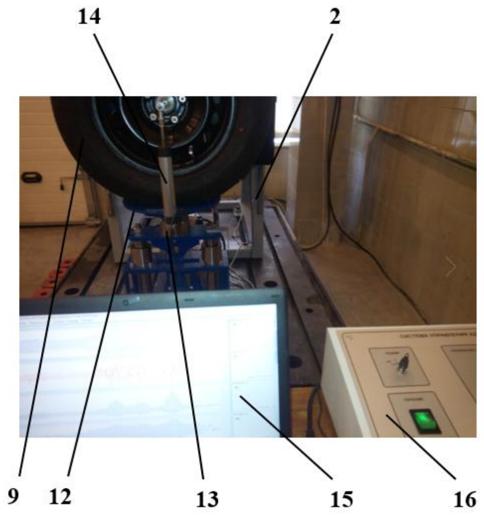

Fig. 10. Stand of the front suspension of the car VOLKSWAGEN PASSAT CC

The sensor 14 actually measures the distance from the center of the wheel 9 to the vibrator support 12, i.e. "Dynamic radius" of the wheel. When the wheel is separated from the support, this sensor also measures the total distance from the wheel center to the vibrator support. However, in this case, the measured value is already equal to the sum of the “static radius” of the wheel and the magnitude of the “wheel bounce” —the distance between the wheel surface and the support.

Thus, the imitation of the movement of the car on irregularities, i.e. imitation of the vertical oscillatory motion of the wheel is carried out by implementing a vertical reciprocating motion of the support 12. Moreover, the speed of movement over unevenness is modeled by selecting the appropriate oscillation frequency of the support 12 and can be smoothly “changed” by adjusting the frequency of rotation of the driving motor 10.

“The height of the irregularities”, i.e. the amplitude of oscillation of the support 12, can be continuously adjusted. However, in our experiments, the “height of the irregularities” was unchanged and was equal to 50 mm.

All measurements were recorded on the PC 15, and the regulation of the frequency of oscillations of the support and the degree of dissipation of the adaptive shock absorber was carried out using the control complex 16.

The emergence of the phenomenon of separation of the wheel from the roadway when driving over irregularities

Movement of the vehicle on unevenness causes vertical oscillations of the wheel 9 and the movable load (car body) 3. At certain speed modes of movement on unevenness (i.e., at certain frequencies of oscillation of the vibrator support 12) and certain settings for the degree of dissipation of the shock absorber, wheel tearing appears 9 from the support 12 [15-22]. In this case, as a rule, the amplitude of the vertical oscillations of the body and the amplitude of the vertical accelerations of the body increase significantly. These circumstances, in aggregate, significantly impair handling, driving safety, dramatically increase the dynamic load of passengers and cargo being carried, while significantly reducing comfort and speed of the vehicle as a whole, and the effectiveness of stabilizing its body position.

Fig. 11 shows a fragment of the waveform test of the front suspension of a VOLKSWAGEN PASSAT CC with a standard suspension, on which the process of separation of the wheel 9 from the support 12 is fixed. Here, curve A shows the force F acting from the side of the wheel 9 on the vibrator support 12, while Fs is the force acting on the support in the static condition of the wheel (when the car is stationary). Curve B shows the value of the vertical acceleration a of the moving load 3 - simulator of the “right front quarter” of the VW PASSAT CC car body. Curve C displays the distance R from the center of the wheel to the support 12 of the vibrator. At the same time, Rs characterizes this distance under the static condition of the car when the car is stationary, and R_0 is numerically equal to the “static radius” of the wheel 9. Curve D shows the vertical movement (oscillations) S of the moving load 3 (car body), Ss determines the vertical position of the body car in a static state of the car when the car is stationary. In these graphs, the abscissa axis is the axis of the “time” t of the process.

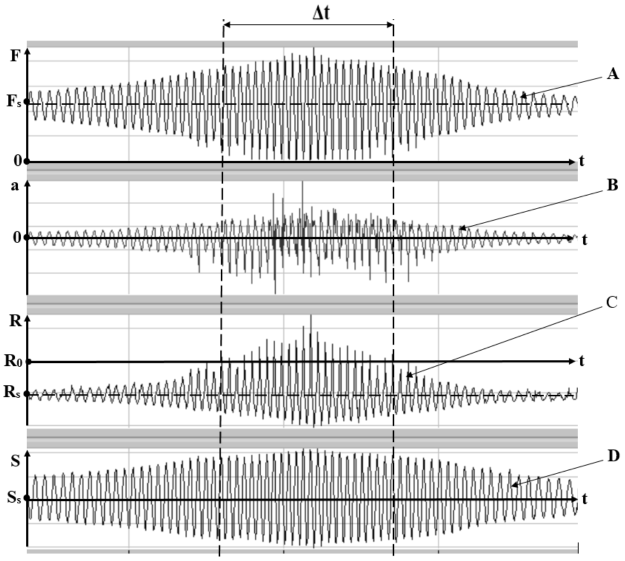

Fig. 11. Fragment of the oscillogram of tests of the front suspension of the car VOLKSWAGEN PASSAT CC with standard design

Note that under the condition

$$R > R_0, \tag{11}$$

i.e., at the section Δt of the oscillogram, the wheel 9 takes off from the support 12.

The movement of the car on unevenness leads to vertical oscillations of the wheel 9 and the movable load (car body) 3. Under certain speeds of a vehicle, unevenness (i.e., at certain frequencies of oscillation of the vibrator support 12) and the corresponding “settings” of the shock absorber, wheel tearing phenomena appear 9 from the support 12. The breaks of the wheels occur on the section Δt of the oscillogram. In this case, as a rule, the amplitude S(t) of the body's vertical oscillations and the amplitude a(t) of the body's vertical accelerations increase significantly, which is clearly recorded on the plot Δt of the oscillogram. These circumstances, in aggregate, significantly impair handling, driving safety, dramatically increase the dynamic load of passengers and cargo being carried, while significantly reducing comfort and speed of the vehicle as a whole, and the effectiveness of stabilizing its body position.

We emphasize that it is precisely at the section Δt of the oscillogram that condition (11) is fulfilled, i.e. the distance R from the center of the wheel periodically exceeds the value of the static radius R_0 of the wheel, while at the same time, the force F from the wheel side to the support 12 periodically decreases to zero, i.e. the wheel 9 periodically detaches from the support 12.

It should also be emphasized that this mode of separation of the wheel is fixed during the implementation of the standard, factory "tuning algorithm" of the shock absorber. These negative phenomena are eliminated in the whole range of oscillation frequencies of the vibrator support (in the entire speed range of the mode of motion of the car on unevenness) due to the use of elastic elements of our design, or through the use of adaptive shock absorbers of our design. Of course, the noted negative phenomena will be even more effectively eliminated with the simultaneous introduction of both elastic elements and adaptive shock absorbers of our structures into the suspension scheme.

For example, Fig. 12 shows a fragment of the waveform test of the front suspension of a VOLKSWAGEN PASSAT CC with a suspension equipped with an adaptive shock absorber of our design.

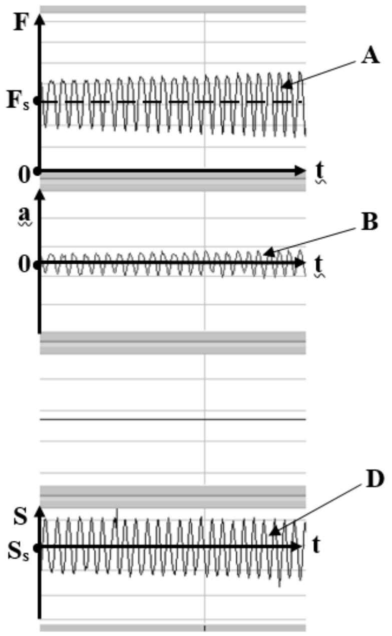

Fig. 12. Fragment of the waveform test of the front suspension of the car VOLKSWAGEN PASSAT CC with the adaptive shock absorber and elastic elements of our designs

Here, during the tests, the sensor fixing the value of the distance R from the center of the wheel to the vibrator support 12 (Fig. 10) was turned off (curve C is absent). Scale in waveforms in Fig. 11 and Fig. 12 is saved.

Even a direct comparison of the waveforms shown in Fig. 11 and Fig. 12 already allows us to draw the following conclusions: the use of the adaptive shock absorber and the elastic element of our designs in the front suspension of the VOLKSWAGEN PASSAT CC allows, in the whole speed range of the driving mode, to be uneven:

1. To exclude the phenomenon of separation of the wheel from the support (from the roadway), which increases the driving safety of the car, improves its handling.
2. To reduce more than halve the vertical accelerations of the body, and, consequently, the dynamic loads on the driver and passengers (compare curves B in Fig. 11 and Fig. 12).
3. To reduce the amplitude of body oscillations by more than two times (compare curves D in Fig. 11 and Fig. 12).

VII. CONCLUSION

1. We have developed new designs: 1) the lockable adaptive shock absorber with a hyper-wide control range of dissipative characteristics; 2) the elastic element with the nonlinear characteristic and the automatic optimization of localization of working zones. Our suspensions allow: 1) implementing the hyper-wide control range of dissipative characteristics; 2) realizing the "self-blocking" mode at any time; 3) implementing any pre-defined dissipative characteristics of the marked hyper-wide control range; 4) adjusting the dissipative characteristics of a vehicle while driving in manual mode, by direct control action, and by automatic control; and they have some other advantages. Usage of our suggested designs of the suspensions will help more effective to solve the problem of stabilization of the vehicle and its body.

2. Summarizing the above, and based on the present state of our experience of work in the development of the adaptive suspension vehicle, the achieved level of our scientific expertise and our research capacity in this field, we can confidently state that, in the case of our proposed designs of the adaptive suspension system, the vehicle is equipped with this suspension system will surpass the known world analogues for technical and economic indicators of quality.

3. We have installed the developed design of the suspension on the car "Lada-Granta." The experimental results confirmed the validity of the theoretical propositions.

4. The comparative experimental simulation tests of the VW PASSAT CC car suspension when it is moving over unevenness have shown that in some speed modes of vehicle movement, wheel separation modes from the supporting surface (from the road surface) inevitably arise. In this case, during the process of separation of the wheel from the surface of the roadway, as well as when "approaching" to this process, the operational characteristics of the vehicle deteriorate significantly. In particular, the wheel contact with the road surface is disturbed, the amplitude of the body's vertical oscillations and the amplitude of the body's vertical accelerations increase significantly, which, in turn, collectively worsens the handling and safety of the vehicle, dramatically increases the dynamic load on passengers and cargo. significantly reducing comfort, speed of the car as a whole, the effectiveness of stabilizing the position of its

body. However, the noted negative phenomena are effectively eliminated in the entire speed range of the mode of movement of the car over irregularities due to the use of adaptive shock absorbers and elastic elements of our structures. It should be noted that a similar effect occurs in the construction of other vehicles.

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